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ADVICE ON TOTAL ALLOWABLE LANDED CATCH FOR THE BAFFIN BAY NARWHAL POPULATION

Narwhal Monodon monoceros
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Figure 1. Approximate winter range of the Baffin Bay narwhal population.

Context

In 2008, Fisheries and Oceans Canada (DFO) Science provided advice on Potential Biological Removals (PBR) and associated Total Allowable Landed Catches (TALC) for the Nunavut narwhal summering stocks. This advice was provided in response to a request from DFO Fisheries and Aquaculture Management (FAM) (DFO 2008). A decision to accept this advice has not yet been made by the co-management partners responsible for the management of narwhals in Canada. In advance of making a decision, FAM requested advice on TALC for the Baffin Bay narwhal population, the aggregate of the summering stocks, as well as the risks of allocating local harvest levels based on the population-level TALC. This information will be used by the Nunavut Wildlife Management Board (NWMB).

SUMMARY

- The Baffin Bay narwhal population is comprised of stocks that summer in the Canadian High Arctic and West Greenland. Four narwhal stocks are known to summer in Canadian waters: the Somerset Island, Admiralty Inlet, Eclipse Sound and East Baffin Island stocks.

- The Total Allowable Landed Catch (TALC) of the Canadian component of the Baffin Bay narwhal population depends on the assumptions made about the distributional behaviour of narwhals that summer in that region.

Canada

- Assuming philopatry of narwhals to specific summering areas, the TALC for the four summering stocks totals 1,123 narwhals per year, but allocation of the catch to communities should be done in a way that avoids exceeding the TALC for any one stock. A TALC applies to a stock regardless of where or when it is hunted.

- Assuming panmixia of narwhals within the Canadian portion of the Baffin Bay population, the lower and upper bounds for the TALC are 428 and 1,245 narwhals per year, respectively.

- There are risks associated with using a population level TALC, including overharvesting of smaller stocks, when the underlying assumption of panmixia is not met.

- It is recommended that management of Baffin Bay narwhals be based on summering stock aggregations until a much better understanding of mixing and site fidelity within the population has been developed. This approach is consistent with previous Science advice and the precautionary approach.

INTRODUCTION

In Canada, narwhals are currently managed at the population level. In 2007, the Nunavut Wildlife Management Board (NWMB) requested that DFO provide information to assist in establishing Total Allowable Harvest[1] (TAH) for narwhals. DFO Science recommended that the Baffin Bay narwhal population be divided into four discrete management units on the basis of summering aggregations and provided sustainable harvest recommendations for each stock (DFO 2008). Since that time, DFO has provided additional scientific information in support of the recommendation to manage the Baffin Bay narwhal population by summering stock rather than by the population as a whole. DFO Science was asked to provide a population level TALC recommendation for the Baffin Bay narwhal population and any limitations associated with using this approach to permit a full comparison of the two alternate approaches to management (i.e., by summering stock versus population).

ANALYSIS

Definition of Baffin Bay narwhal population

The Baffin Bay narwhal population occupies Baffin Bay and adjacent waters in winter (Fig. 1). In summer, a large component of the population aggregates in Canada, in areas ranging from East Baffin Island coastal waters to the High Arctic archipelago (Richard et al. 2010). The remainder summer in West Greenland waters, particularly in Inglefield Bredning and Melville Bay. If Baffin Bay narwhals are to be managed at the population level, management should consider the entire population including those narwhals that summer in Greenland and are harvested there. However, the following science advice only considers the information available for those Baffin Bay narwhals that summer in Canada. It also assumes that spatial and temporal patterns of hunting will not change.

[1] Total Allowable Harvest is the term used under the Nunavut Land Claims Agreement for the amount of a wildlife stock or population that can be lawfully harvested (i.e., the harvest limit). The term used in this and previous science advice on narwhal hunt limits is Total Allowable Landed Catch (TALC), emphasizing that the limit is set on the landed catch from a stock, after discounting for hunting loss rates.

The Canadian portion of the Baffin Bay population consists of at least four narwhal stocks which aggregate in summer: the Somerset Island, Admiralty Inlet, Eclipse Sound and East Baffin Island stocks (DFO 2010, Richard 2010) (Fig. 2). The Somerset Island and East Baffin Island stocks cover large areas and may have further sub-stock structuring. In addition, narwhals are known to occur elsewhere in the High Arctic during summer (Fig. 2). We have no assessment of their number and seasonal movements or their relationship to other Baffin Bay narwhals. Thus we only consider the four known narwhal stocks that comprise the Canadian component of the Baffin Bay population. The Northern Hudson Bay narwhal population is recognized as a geographically separate and genetically distinct population and is not being considered here.

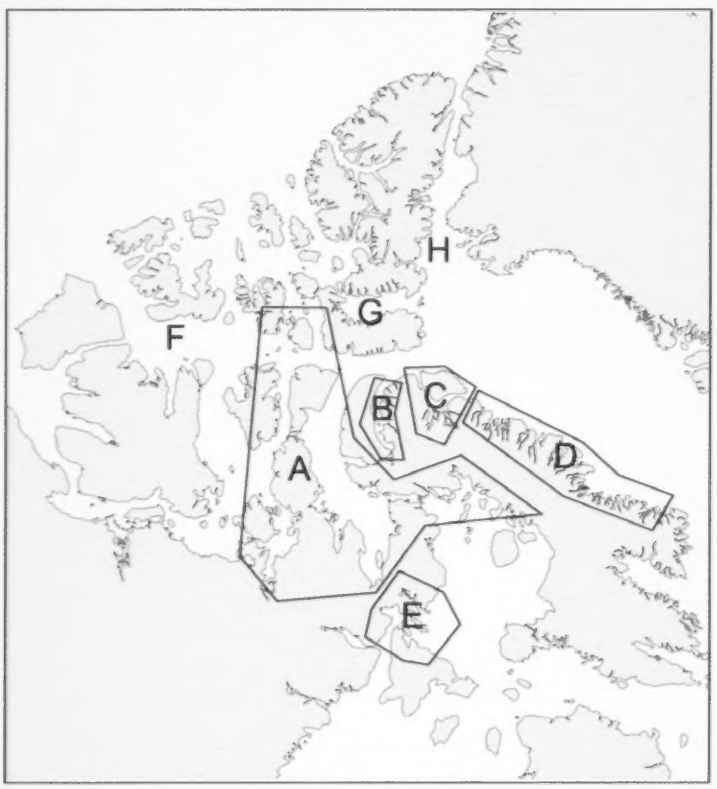

Figure 2. Approximate boundaries of areas where Canadian stocks of narwhals aggregate in summer: A - Somerset Island, B - Admiralty Inlet, C - Eclipse Sound, D - East Baffin Island, E - Northern Hudson Bay. Other areas where narwhals are known to occur in summer: F - Parry Islands, G - Jones Sound, H - Smith Sound) (modified from DFO 2010).

History of Canadian High Arctic narwhal surveys

To provide context for the subsequent discussion of TALC for this population, it is helpful to review estimates of narwhal numbers for the Canadian component of the Baffin Bay narwhal population (as defined above). A first abundance estimate was derived from cliff counts and aerial surveys of Lancaster Sound in spring and early summer of 1976 (Davis et al. 1978). The authors suggested that between 20,000 and 30,000 narwhals migrated past the mouth of Lancaster Sound towards their summering areas in the Canadian High Arctic (Table 1). There was no accounting for narwhals summering along the coast of East Baffin Island. If the estimate is corrected for diving animals using a multiplier derived for recent fully-corrected surveys (i.e., 2.9X to account for whales not within 2 m of the surface) (Richard et al. 2010), that estimate

increases to 58,000-87,000 narwhals (Table 1), although it is questionable whether the same correction should be applied to cliff counts.

Fallis et al. (1983) conducted reconnaissance and systematic surveys for narwhals in Admiralty Inlet in 1975 and 1976. They extrapolated a surface estimate of 9,683 narwhals from surveys conducted on 28 July 1975 (Table 1).

Smith et al. (1985) surveyed Prince Regent Inlet and Barrow Strait in August 1981 and calculated a surface estimate of about 11,000 narwhals (Table 1) for those two areas. They made some assumptions about numbers of narwhals in Peel Sound and Admiralty Inlet and concluded there were between 13,200 and 18,000 narwhals in the Canadian High Arctic. Smith et al. (1985) thought there might be about 2,000 narwhals in Peel Sound. They added 2,117 narwhals for Admiralty Inlet as calculated by Fallis et al. (1983) based on systematic and reconnaissance surveys conducted on 9 August 1975. They made no allowance for Gulf of Boothia, Eclipse Sound or east Baffin Island or for animals missed because they were diving. A 2.9X correction for the Barrow Strait-Prince Regent Inlet survey (Somerset Island Stock) yields an estimate of about 32,000 narwhals.

Richard et al. (1994) conducted aerial photo surveys in Peel Sound, Prince Regent Inlet, Admiralty Inlet and part of Eclipse Sound in 1984. The total surface estimate was about 18,000 animals which, when corrected for diving animals (the instantaneous for photographic surveys is 3.1X correction, see Asselin and Richard 2011), yields an abundance estimate of about 57,000 narwhals (Table 1). It should be kept in mind that their survey coverage did not include the Gulf of Boothia, Barrow Strait or East Baffin Island.

Innes et al. (2002) produced a fully corrected abundance estimate of 45,000 narwhals based on aerial surveys of Peel Sound, Prince Regent Inlet and Barrow Strait (Table 1). They did not survey the Gulf of Boothia, Eclipse Sound or East Baffin Island fiords. Consequently, their estimate applies only to the Somerset Island stock. In Peel Sound, they estimated a fully-corrected number of about 5,000 narwhals, which is about 2.5X what Smith et al. (1985) suggested could be found there based on their surface counts, but close to the number that would result from applying a 2.9X correction for diving animals.

In the month of August, from 2002 to 2004, Richard et al. (2010) surveyed Prince Regent Inlet, Gulf of Boothia, Admiralty Inlet, Eclipse Sound, Barrow Strait and East Baffin fiords. They estimated a total of about 66,000 narwhals (Table 1), assuming narwhals were philopatric to their summering areas. They had not been able to survey Peel Sound and had concerns about the accuracy of the Admiralty Inlet survey due to the visibility conditions and incomplete coverage. The fully-corrected estimate for Prince Regent and Gulf of Boothia was an estimated 28,000 narwhals for August 2002, lower than the 45,000 estimated in 1996. The 1996 survey had higher densities of narwhals in Prince Regent Inlet and had also covered Peel Sound. The ice cover in the Gulf of Boothia was heavier in 1996 so that stratum was not covered during the 1996 survey. It is possible that the difference between the two survey estimates is due to the fact that Prince Regent Inlet had little ice in 2002, and that the Gulf of Boothia pack ice was more open, allowing for a broader distribution of narwhals. The combination of not surveying Peel Sound and the broader distribution of narwhals in 2002 may have resulted in lower abundance estimates in 2002 than in 1996.

Table 1. Summary of abundance estimates (with coefficients of variation, and lower and upper confidence limits) for the Canadian portion of the Baffin Bay narwhal population. Note: No single survey covered the entire range of narwhals in summer. Some surveys covered the summer aggregations and are summed to give an estimate (albeit incomplete) of the Canadian component of the Baffin Bay narwhal population.

Stock or Area	Dates	Year	Estimate	CV	LCL	UCL	Source	Technique
Canadian High Arctic (CHA)	May-July	1976	20,000-30,000				Davis et al. 1978	Cliff counts at mouth of Lancaster Sound
CHA corrected			*58,000-87,000*					2.9X diving correction and rounded to nearest 1000
Admiralty Inlet	July	1975	9,683				Fallis et al. 1983	Surface extrapolation from systematic survey densities
Prince Regent Inlet and Barrow St.	August	1981	11,142		9,035	13,891	Smith et al. 1985	Surface estimate from systematic strip transects
PR&BS corrected			*32,312*					2.9X diving correction and rounded to nearest 1000
Eclipse Sound	August	1984	1,218	0.26			Richard et al. 1994	Surface count - systematic random photographic surveys
Admiralty Inlet	"	1984	5,556	0.22	3,759	8,213	" "	" "
Prince Regent Inlet	"	1984	9,754	0.18			" "	" "
Peel Sound	"	1984	1,701	0.17			" "	" "
CHA		1984	18,229[2]	0.10	14,724	21,258	" "	Surface count - systematic random photographic surveys
CHA corrected			*56,510*					3.1X diving correction
Barrow Strait	late July-early August	1996	5,898	0.75			Innes et al. 2002	Corrected count - systematic random visual surveys
Peel Sound	" "	1996	5,240	0.60			" "	" "
Prince Regent	" "	1996	34,159	0.35			" "	" "
Somerset Island stock area total		1996	45,358	0.35			" "	
Eclipse Sound	August	2002	7,578	1.26			Richard et al. 2010	Systematic random visual surveys - uncorrected
Eclipse Sound	August	2002	*21,264*	1.26	3,143	143,877	" "	Diving correction derived from methods in Richard et al. 2010
Admiralty Inlet	August	2003	5,362	0.50	1,920	12,199	" "	" "
P.Regent-G.Boothia	"	2002	27,656	0.54	9,080	66,061	Richard et al. 2010	Corrected count - systematic random visual surveys
East Baffin Island	"	2003	10,073	0.31	5,333	17,474	" "	" "
Eclipse Sound	"	2004	20,225	0.36	9,471	37,096	" "	" "
Barrow Strait	"	2004	2,925	0.46	1,140	6,270	" "	" "
Total for SI, AI (2003), ES and EB			66,241				" "	
Admiralty Inlet	"	2010	18,049	0.23	11,613	28,053	Asselin & Richard 2011	Corrected count – mean of two systematic random visual surveys and photographic surveys of aggregation areas
Total for SI (PR-GB 2002, BS 2004), AI (2010), ES (2004) and EB (2003)			78,928					
Total for SI (1996), AI (2010), ES (2004) and EB (2003)			93,705					

Surveys were flown in Admiralty Inlet both in August 2003 and 2004 but in both years were affected by lack of coverage and poor visibility conditions, as well as extreme clumping of

[2] The original sum of the survey strata was incorrectly reported as 17,991 in Richard et al. 1994.

narwhals off transect (Richard et al. 2010). The August 2003 estimate is presented in Table 1. Because that survey was considered unreliable, a new survey was flown in August 2010. Asselin and Richard (2011) estimated a fully-corrected narwhal population size of about 18,000 narwhals for Admiralty Inlet (Table 1), a number more than three times the previous estimate.

Abundance of Canadian High Arctic Narwhals

The behaviour of narwhals influences the conclusions that can be drawn from available population estimates. If narwhals show fidelity to certain summering areas year after year, then it is possible to sum the abundance estimates for different summering stocks even when they are obtained in different years. On the other hand, if narwhals do not show fidelity to summering areas and instead mix randomly within the population, they may not be distributed between aggregation areas in the same way every year. This means that summing estimates from different years could over-estimate the population by counting the same animals more than once.

There is evidence that Canadian summering stocks do not mix in summer (DFO 2010, Richard 2010). Furthermore, there is growing evidence from tracking data (Richard 2010; Heide-Jørgensen and Richard, unpubl. data), that the narwhals that aggregate in different summering areas show philopatry, i.e., they return to the same summering areas every year, presumably because they have learned to do so from their mothers. Migratory and gregarious species, such as narwhals and other odontocetes, tend to learn from one another and older animals in their migrating group. This can produce habitual patterns, one of which is a behaviour called "natal philopatry". It has been demonstrated for beluga (*Delphinapterus leucas*), killer whale (*Orcinus orca*), bottlenose dolphin (*Tursiops truncatus*), and long-finned pilot whale (*Globicephala melas*), and it has been hypothesized for several other species of odontocetes (Mann et al. 2000). Although the evidence for summering philopatry in narwhals is largely based on tagging results and the number of tagged animals is limited, all those that retained their tags long enough, did return to the location where they were originally tagged. There are some contaminant data which also supports summering philopatry. Genetic evidence indicates some differences but these can't be conclusive with the current samples. So, if one assumes that the Baffin Bay narwhal population separates into summering stocks composed of animals that are philopatric to certain areas and do not mix in summer, then the mean population estimate for the Canadian High Arctic portion of the Baffin Bay population is approximated by the sum of the stock estimates.

Two total mean estimates are presented for the Canadian portion of the Baffin Bay population (Table 1) based on the assumption that narwhals show fidelity to summering areas. Both estimates include the best strata estimates for the Admiralty Inlet stock (2010), the Eclipse Sound stock (2004) and the East Baffin Stock (2003). One estimate includes the 2002 Prince Regent Inlet-Gulf of Boothia-Barrow Strait survey results, which produces a total mean population estimate of about 79,000 narwhals. The other estimate includes the 1996 Prince Regent Inlet-Peel Sound-Barrow Strait survey results, which produces a total mean population estimate of about 96,000 narwhals.

However, if one assumes complete mixing among narwhals that summer in the Canadian High Arctic (i.e., panmixia), then the abundance estimate for the Canadian portion of the Baffin Bay population is more difficult to obtain because there has never been a survey conducted over the entire range in any one season. A minimum estimate of population size can be calculated from results obtained during the year in which the surveys covered the largest portion of the range. In 2002, surveys covered Prince Regent Inlet and Eclipse Sound and the mean estimates for those areas totaled about 49,000 narwhals. This is lower than the sum of estimates for the

summering stocks, which are approximately 80,000 or 96,000 depending on which Somerset Island estimate is used.

Total Allowable Landed Catch

TALCs for the four summering stocks that comprise the Canadian portion of the Baffin Bay narwhal population were proposed in previous advice (DFO 2008, Richard 2008). They were based on calculations using the Potential Biological Removal (PBR) method (Wade 1998) modified to account for hunting losses:

$$TALC = \frac{PBR}{LRC} \qquad (1)$$

Where:

$PBR = 0.5 \times R_{Max} \times \hat{N}_{Min} \times F_r$

LRC = Hunting loss rate correction

R_{Max} = Maximum rate of increase for the population (0.04)

$\hat{N}_{Min}$ = 20th percentile of the log-normal distribution of the estimated stock or population size

F_r = Recovery factor

Table 2. Total Allowable Landed Catch (TALC) estimates obtained by the PBR method with correction for hunting losses. A recovery factor of 1 was used to calculate PBR.

Stock or Population	N_{min}	Loss rate correction	PBR	TALC
ASSUMING STOCK PHILOPATRY				
Somerset Island (1996)	34,068	1.28	681	532
Admiralty Inlet (2010)	14,936	"	299	233
Eclipse Sound (2004)	15,074	"	301	236
East Baffin (2003)	7,805	"	156	122
Sum of summering stock TALCs				**1,123**
ASSUMING PANMICTIC POPULATION AND CONSTANT SUMMERING GROUND PROPORTIONS				
Lower bound				
Prince Regent-Gulf of Boothia (2002)	18,068	1.28	361	282
Eclipse Sound (2002)	9,356	"	187	146
E High Arctic Population				**428**
Upper bound				
SI (1996) + AI (2010) + ES (2004) + EB (2003)	79,673	1.28	1,593	**1,245**

Assuming philopatry of narwhals to specific summering areas, the TALCs for the stocks belonging to the Canadian portion of the Baffin Bay population are given in Table 2. This includes the previous advice (DFO 2008) updated with the results from the 2010 Admiralty Inlet survey (Asselin and Richard 2011). The sum of those TALCs is 1,123 narwhals, though the

allocation of the catch to communities must be done in a way that avoids exceeding the TALC for each stock. A TALC applies to a stock regardless of where or when it is hunted.

Assuming panmixia of narwhals within the Canadian portion of the Baffin Bay population, the TALCs for the two areas surveyed in 2002 (i.e., the greatest narwhal survey coverage for the region in recent years) total 428 narwhals. This is a lower bound for the TALC using the best available data collected from a single year. The upper bound for the TALC was also calculated. N_{min} for the PBR calculation was calculated as follows:

$$\hat{N}_{\min} = N / \exp(0.842(\ln(1 + CV(N)^2)^{1/2}) \qquad (2)$$

Where N is the sum of the best estimates of abundance in the separate summering areas and CV is estimated from the root sum of squares of the standard errors of these best estimates. The upper bound for the TALC using this method is 1,245.

There are several issues associated with estimating levels of abundance, PBR and TALCs based on an assumption of a panmictic population. Firstly, the existing evidence from tagging studies and the literature suggests the Baffin Bay population is not well-mixed. Secondly, a complete survey of the Baffin Bay population in any one season is not available, therefore confidence in abundance estimates or survey precision for the Baffin Bay population is uncertain. This has an effect on N_{min} and the PBR. Thirdly, the best estimates of population size are dated. Fourthly, the population abundance and harvest from the Greenland portion of the Baffin Bay population should be included in these analyses and this has not been done. For example, using the average from five years (2003-2007) Nunavut (excluding Repulse Bay) harvested 423 narwhal/year whereas West Greenland harvested 400 (JCNB 2009). Finally, some summering aggregations (e.g., Eastern Baffin Island) are small and a population level TALC taken from these areas could deplete local aggregations, as was the case for Ungava Bay beluga. It is highly probable that not all current summering stocks could sustain the same level of harvest. The risk of over exploiting summering stocks, especially small ones, is a possibility. Thus it is not recommended that Baffin Bay narwhals be managed at a population level TALC until a much better understanding of mixing and site fidelity has been developed and knowledge of the Greenland portion of the population has been considered. The current advice is consistent with the previous science advice to manage Baffin Bay narwhals on the basis of summering stock aggregations.

Sources of uncertainty

Most of the survey estimates used in the analysis are dated, particularly the 1996 Somerset Island stock estimate. In some cases, results have been quite different between surveys conducted more than once in the same areas. This suggests that sampling error may be larger than is indicated by the estimated CVs. The estimates of loss rate used in the modified PBR calculation are based on an assessment from self-reported hunting loss rates from five communities that were considered realistic (Richard 2008), but there has been no independent assessment of loss rates in different hunting locations or seasons.

CONCLUSIONS AND ADVICE

In conclusion, the lower and upper bounds of the TALC for the Canadian portion of the Baffin Bay population calculated at the population level are 428 and 1,245 narwhals per year, respectively. For comparison, the sum of TALCs for the four known summering stocks is 1,123 narwhals per year. The revised TALC for Admiralty Inlet, based on the 2010 surveys (Asselin and Richard 2011), was incorporated into the calculations for the two latter TALCs.

There are several risks associated with allocating harvest levels based on a population-level TALC. Managing at the population level depends on narwhals being well mixed which existing evidence indicates is not the case. The population has not been surveyed in its entirety in one year and the Greenland portion of the population has not been included in the estimates of population abundance which increases uncertainty in the accuracy of the TALC. The TALC calculations are based on dated surveys. Finally, some summering aggregations (e.g., Eastern Baffin Island) are small and a population level TALC taken from these areas could deplete local concentrations. For these reasons, it is not recommended that Baffin Bay narwhals be managed at the population level TALC.

The precautionary approach is to manage narwhals on a stock-by-stock basis, until new information indicates that a change in strategy is warranted.

SOURCES OF INFORMATION

This Science Advisory Report is from the April 1, 2011 meeting of the National Marine Mammal Peer Review Committee: Baffin Bay Narwhal - Population level sustainable harvest (PBR, TALC) calculation. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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